CERES Aqua Edition3A SSF Surface Fluxes - Accuracy and Validation

One of the principal objectives for the CERES data products is to provide improved estimates of surface fluxes (net and downward) for shortwave (SW) and longwave (LW) radiation. To achieve this objective, considerable effort has been focused upon obtaining consistent fluxes at the surface, within the atmosphere, and at the top of the atmosphere, all of which are produced as part of the CERES SARB data product using a detailed radiative transfer model and CERES Single Scanner Fluxes (SSF) as the input data. The development and implementation of the SARB algorithm, however, has proven to be a very complex undertaking, which required a considerable amount of time just to produce and validate the first SARB results. As an alternative, an effort was undertaken to use much simpler and faster models that were already available and validated, and which could quickly produce the surface fluxes. This data quality summary is concerned with these Surface-Only Flux Algorithms (SOFA) that either:

- Associate surface fluxes directly with broadband CERES TOA fluxes using the methods provided by Z. Li, H. G. Leighton and R. D. Cess (1993), *J. Climate*, **6**, 1764-1772, or W. L. Darnell W. F. Staylor, S. K. Gupta, N. A. Ritchey and A. C. Wilber (1992), *J. Geophys. Res.*, **97**, 15741-15760 for the SW surface fluxes, and by A. K. Inamdar and V. Ramanathan (1997), *Tellus*, **49B**, 216-230 for the clear-sky LW surface fluxes.

- Or use a simple radiative parameterization to directly calulate the surface fluxes from meteorological parameteres as provided by S. K. Gupta (1989), *J. Climate*, **2**, 305-320, and in S. K. Gupta, W. L. Darnell, and A. C. Wilber (1992), *J. Appl. Meteor.*, **31**, 1361-1367 that utilize various retrieved meteorological parameters to estimate surface downward LW fluxes, which are effectively decoupled from the TOA fluxes for cloudy sky conditions.

Consequently, these simpler SSF surface flux parameterizations are more comparable to results used in past analyses of surface radiation data sets based on ERBE or geostationary data. In general, however, they are not expected to be as precise as the CERES SARB surface fluxes, though they do represent an independent method to get to the more difficult surface flux estimates.

The CERES SSF Edition 3 data product provides 4 surface flux algorithm results:

1. Shortwave Flux Model A, Daytime only, Clear-sky only
    - Net surface fluxes use Li et al. (1993).
    - Downward surface fluxes use Li et al. (1993) for net and Z. Li and L. Garand (1994), *J. Geophys. Res.*, **99**, 8335-8350 for the surface albedo.

2. Shortwave Flux Model B, Daytime only, Clear and All-sky
    - Net and downward surface fluxes use the Langley Parameterized Shortwave Algorithm (LPSA) as introduced by Darnell et al. (1992) and further described in S. K. Gupta, D. P. Kratz, P. W. Stackhouse and A. C. Wilber (2001), NASA/TP-2001-211272.

3. Longwave Flux Model A, Daytime and Nighttime, Clear-sky only
    - Net and downward surface fluxes uses Inamdar and Ramanathan (1997).

4. Longwave Flux Model B, Daytime and Nighttime, Clear and All-sky
    - Net and downward surface fluxes use the Langley Parameterized Longwave Algorithm (LPLA) as described in Gupta (1989) and Gupta, Darnell, and Wilber (1992).

For Terra and Aqua surface fluxes, clear-sky conditions are defined for CERES footprints with an imager determined cloud cover percentage less than 0.1%. Thus, to be consistent with the angular distribution models, our validation effort has also taken clear-sky to be defined as a CERES footprint with an imager determined cloud cover percentage less than 0.1%. The SSF surface fluxes are being validated using both theoretical analyses and simultaneous matching of satellite data to a range of surface sites. Preliminary results are discussed in the sections which follow.

The CERES SSF surface flux estimates for Edition 3A are derived using the Terra data starting with March 2000 and running through February 2010, and the Aqua data starting with July 2002 and running through February 2010. The coincident surface fluxes are nominally gathered from the Atmospheric Radiation Measurement (ARM) networks which include the Southern Great Plains (SGP), Tropical Western Pacific (TWP) and North Slope Alaska (NSA) sites, the Climate Modeling and Diagnostic Laboratory (CMDL) network, the Baseline Surface Radiation Network (BSRN) and the Surface Radiation Budget Network (SURFRAD). Unless otherwise noted, surface site fluxes are 1 minute averages and are compared to the CERES footprint which includes the surface site.

A detailed discussion concerning the validation and inter-comparison studies involving the CERES Edition 2B data from both the Terra and Aqua satellites has been presented in "Validation of the CERES Edition 2B Surface-Only Flux Algorithms" by D. P. Kratz, S. K. Gupta, A. C. Wilber and V. E. Sothcott (2010), *J. Appl. Meteor. Climatol.*, **49**, 164-180, doi:10.1175/2009JAMC2246.1.

From lessons learned during the validation studies of the surface longwave flux algorithms used in the CERES processing, several improvements were developed, tested and then implemented for the longwave models. A detailed discussion concerning these efforts has been presented in "Improvement of Surface Longwave Flux Algorithms Used in CERES Processing" by S. K. Gupta, D. P. Kratz, P. W. Stackhouse, A. C. Wilber, T. Zhang and V. E. Sothcott (2010), *J. Appl. Meteor. Climatol.*, **49**, 1579-1589, doi:10.1175/2010JAMC2463.1.

The validation results reported in this data quality summary compare Terra and Aqua Edition 3A for the period running from January 2008 through December 2009.

Shortwave Downward Flux Validation

CERES processing uses two very different models to produce the shortwave surface fluxes. While shortwave Model A was formulated to produce net shortwave surface fluxes for all-sky conditions, validation efforts demonstrated that this model could only reliably produce downward shortwave surface fluxes for clear-sky conditions. In contrast, shortwave Model B, which was formulated to produce downward shortwave surface fluxes for all-sky conditions, was found to have the capability to produce both downward and net shortwave surface fluxes reliably for all-sky conditions. These models are both part of our validation effort, and will be discussed separately.

Clear-sky Shortwave Downward Flux Validation: Model A

Validation studies of the TRMM Edition 2B surface fluxes demonstrated that shortwave Model A overestimated surface insolation at the ARM Central Facility by approximately 30 W m^{-2}. Considering that such biases were not observed for pristine high-latitude surface sites, it was hypothesized that the effects of aerosols could be the cause. Thus, an aerosol correction factor based on the K. Masuda, H. G. Leighton and Z. Li (1995), *J. Climate*, **8**, 1615-1629 method, which also uses the GFDL climatological aerosols described in J. M. Haywood, V. Ramaswamy and B. J. Soden (1999), *Science*, **283**, 1299-1303) was incorporated into shortwave Model A. The use of the Masuda et al. (1995) method with the GFDL climatological aerosols has already been shown to produce a significant improvement to shortwave Model A. For Edition 3, however, the GFDL aerosols have been replaced with a 70 month MATCH aerosol climatology, which provides a further significant improvement.

Unlike many of the earlier versions of the SSF Data Quality Summary, this version groups together surface sites with similar characteristics: Continental, Desert, Coastal, Island and Polar, rather than grouping together surface sites from a single source. This allows for a better understanding of which surface and climatological types are the most problematic.

The following table shows the results for of the clear-sky shortwave Model A retrievals as compared to the surface measured fluxes. Biases are defined to be CERES derived surface fluxes minus surface measured fluxes.

Downward Shortwave Model A Comparisons, Clear-Sky, 1 min data

Scene Type	# of Points	Mean Bias	RMS Difference	Standard Deviation
Continental	400	-13.80 W m^{-2} (-2.03%)	26.05 W m^{-2} (3.84%)	21.85 W m^{-2} (3.22%)
Desert	313	-34.17 W m^{-2} (-4.11%)	50.66 W m^{-2} (6.10%)	32.48 W m^{-2} (3.91%)
Coastal	105	-8.00 W m^{-2} (-1.15%)	19.68 W m^{-2} (2.83%)	17.73 W m^{-2} (2.55%)
Island	26	25.66 W m^{-2} (2.81%)	113.23 W m^{-2} (12.39%)	60.07 W m^{-2} (6.57%)
Polar	160	-33.51 W m^{-2} (-7.95%)	3.9.41 W m^{-2} (9.35%)	18.90 W m^{-2} (4.48%)

All-sky Shortwave Downward Flux Validation: Model B

CERES processing also makes use of a second shortwave model to produce surface fluxes. Unlike Model A, Model B produces fluxes for both clear and cloudy-sky conditions. The combination of clear and cloudy conditions is often referred to as all-sky conditions. Since Model B was formulated to be an all-sky model, this model has been applied to a wider range of sky conditions than Model A; however, validation efforts have demonstrated that improvement is necessary for both clear-sky and cloud-sky retrievals. Thus, a number of improvements have been implemented into shortwave model B for Edition 3, and more improvements are already being developed for Edition 4. The following provides a list of Model B improvements for Edition 3.

1. A correction has been made to a code limitation that prevented flux calculations for ozone column abundances that exceeded 500 Dobson Units.

2. A modification was made to the formulation to provide a more realistic dependence of the instantaneous surface albedo on the cosine of the solar zenith angle.

3. For Terra processing, the monthly climatology of clear-sky TOA albedos that had been based on 48 months of ERBE data were replaced by monthly climatology of clear-sky TOA albedos based on 70 months of Terra data. This substitution led to a significant improvement in the downward shortwave flux retrievals at the surface (See Kratz et al, 2010).

4. For Aqua processing, the monthly climatology of clear-sky TOA albedos that had been based on 46 months of Terra data were

replaced by monthly climatology of clear-sky TOA albedos based on 70 months of Terra data.

The following table shows the results for of the clear-sky shortwave Model B retrievals as compared to the surface measured fluxes. Biases are defined to be CERES derived surface fluxes minus surface measured fluxes.

Downward Shortwave Model B Comparisons, Clear-Sky, 1 min data

Scene Type	# of Points	Mean Bias	RMS Difference	Standard Deviation
Continental	404	-26.00 W m^{-2} (-3.83%)	34.04 W m^{-2} (5.01%)	18.12 W m^{-2} (2.67%)
Desert	318	-33.04 W m^{-2} (-3.99%)	44.22 W m^{-2} (5.34%)	29.36 W m^{-2} (3.54%)
Coastal	106	-12.33 W m^{-2} (-1.77%)	20.24 W m^{-2} (2.90%)	15.61 W m^{-2} (2.24%)
Island	26	2.17 W m^{-2} (0.24%)	108.79 W m^{-2} (11.90%)	55.86 W m^{-2} (6.11%)
Polar	172	2.65 W m^{-2} (0.67%)	19.28 W m^{-2} (4.84%)	17.96 W m^{-2} (4.51%)

Results are also presented for the all-sky Model B retrievals. To reduce the considerable variance introduced by broken cloud fields, the surface data is averaged over the 60 minutes centered on the time of the satellite overpass. Note, the variance that is introduced by broken cloud fields is far greater than that introduced by the temporal averaging.

The following table shows the results for of the all-sky shortwave Model B retrievals as compared to the surface measured fluxes. Biases are defined to be CERES derived surface fluxes minus surface measured fluxes.

Downward Shortwave Model B Comparisons, All-Sky, 60 min data

Scene Type	# of Points	Mean Bias	RMS Difference	Standard Deviation
Continental	3225	7.87 W m^{-2} (1.53%)	89.09 W m^{-2} (17.38%)	78.14 W m^{-2} (15.24%)
Desert	1177	-15.87 W m^{-2} (-2.12%)	86.71 W m^{-2} (11.56%)	76.49 W m^{-2} (10.20%)
Coastal	758	19.12 W m^{-2} (3.64%)	73.10 W m^{-2} (13.92%)	62.19 W m^{-2} (11.84%)
Island	1167	41.93 W m^{-2} (6.28%)	128.53 W m^{-2} (19.26%)	107.00 W m^{-2} (16.03%)
Polar	4472	-6.52 W m^{-2} (-2.77%)	81.88 W m^{-2} (34.75%)	76.12 W m^{-2} (32.30%)

Longwave Downward Flux Validation

As with the shortwave, CERES processing uses two very different models to produce the longwave surface fluxes. Longwave Model A was specifically formulated to produce longwave surface fluxes for clear-sky conditions, while longwave Model B was formulated for all-sky conditions. These models are both part of our validation effort, and will be discussed separately.

Despite their rather significant differences, both longwave Models A and B have been significantly improved through the implementation of a near-surface air-temperature constraint that manages conditions where the surface temperature greatly exceeds the overlying air temperatures (See Gupta et al, 2010). In addition, a second code modification was applied to both longwave Models A and B to manage temperature inversion conditions where the surface temperature falls below the overlying air temperatures. Note, LW Model B was modified to calculate cloud effects correctly for high altitude regions such as Tibet, where cloud base heights were frequently unavailable from the SSF and were not correctly estimated in the original code.

Clear-sky Longwave Downward Flux Validation: Model A

Longwave Model A uses CERES-derived window and non-window TOA fluxes as well as the meteorological profiles to obtain surface fluxes for clear sky conditions. Biases are defined to be CERES derived surface fluxes minus surface measured fluxes. As demonstrated by the following table, the results from longwave Model A are found to be in good agreement with the surface measurements for all the sites that were considered. It should be noted that a significant modification was applied to longwave Model A between the production of TRMM Edition

2A and 2B. This modification now allows for global ocean and land application of Model A for clear-sky conditions.

The following table shows the results for of the clear-sky longwave Model A retrievals as compared to the surface measured fluxes. Biases are defined to be CERES derived surface fluxes minus surface measured fluxes.

Downward Longwave Model A Comparisons, Clear-Sky, 1 min data

Scene Type	# of Points	Mean Bias	RMS Difference	Standard Deviation
Continental	1268	-3.20 W m^{-2} (-1.15%)	19.49 W m^{-2} (7.03%)	19.12 W m^{-2} (6.90%)
Desert	752	-2.41 W m^{-2} (-0.79%)	11.02 W m^{-2} (3.63%)	10.51 W m^{-2} (3.46%)
Coastal	250	1.86 W m^{-2} (0.65%)	9.82 W m^{-2} (3.45%)	9.64 W m^{-2} (3.38%)
Island	52	-1.53 W m^{-2} (-0.39%)	11.44 W m^{-2} (2.90%)	10.17 W m^{-2} (2.58%)
Polar	426	-10.52 W m^{-2} (-8.79%)	14.97 W m^{-2} (12.51%)	8.50 W m^{-2} (7.11%)

Theoretical studies and validation studies employing data from Central Equatorial Pacific Experiment (CEPEX), reported by Inamdar and Ramanathan (1997), are consistent with our results. The parameterization over land surfaces was initially developed using a limited set of emissivity data available from IRIS measurements aboard NIMBUS 4 and is described in Prabhakara and Dalu (1976), *J. Geophys. Res.*, **81**, 3719-3724. The current version of longwave Model A, however, was developed using the global emissivity maps developed by A. C. Wilber, D. P. Kratz and S. K. Gupta (1999), NASA/TP-1999-209362 and thus can be applied to the extra-tropics as well as to the tropics. Other possible sources of errors include:

1. Specification of the true radiating temperature (especially land surfaces);
2. Errors in scene identification;
3. Emissions from aerosols in the boundary layer. For instance, Inamdar and Ramanathan (1997) noted that sensitivity studies had revealed that thick haze in the boundary layer (visibilities less than 15 km) could increase the downward emissions by about 3 to 5 W m^{-2}.

All-sky Longwave Downward Flux Validation: Model B

Longwave Model B uses the meteorological profiles and CERES MODIS-derived cloud properties, but not the CERES-derived TOA fluxes, to obtain surface fluxes for clear and all-sky conditions. As demonstrated by the following tables, the results from longwave Model B are found to be in good agreement with the surface measurements at all the sites.

The following table shows the results for of the clear-sky longwave Model B retrievals as compared to the surface measured fluxes. Biases are defined to be CERES derived surface fluxes minus surface measured fluxes.

Downward Longwave Model B Comparisons, Clear-Sky, 1 min data

Scene Type	# of Points	Mean Bias	RMS Difference	Standard Deviation
Continental	1279	-6.60 W m^{-2} (-2.38%)	20.12 W m^{-2} (7.26%)	18.95 W m^{-2} (6.84%)
Desert	760	-5.84 W m^{-2} (-1.92%)	14.42 W m^{-2} (4.75%)	13.15 W m^{-2} (4.33%)
Coastal	252	-4.05 W m^{-2} (-1.42%)	11.56 W m^{-2} (4.05%)	10.75 W m^{-2} (3.77%)
Island	53	2.53 W m^{-2} (0.64%)	11.44 W m^{-2} (2.90%)	10.95 W m^{-2} (2.78%)
Polar	430	-4.12 W m^{-2} (-3.44%)	9.42 W m^{-2} (7.86%)	8.47 W m^{-2} (7.06%)

The following table shows the results for of the all-sky longwave Model B retrievals as compared to the surface measured fluxes. Biases are defined to be CERES derived surface fluxes minus surface measured fluxes.

Downward Longwave Model B Comparisons, All-Sky, 1 min data

Scene Type	# of Points	Mean Bias	RMS Difference	Standard Deviation
Continental	6480	-7.57 W m^{-2} (-2.45%)	25.22 W m^{-2} (8.16%)	24.03 W m^{-2} (7.77%)
Desert	2379	-1.07 W m^{-2} (-0.33%)	18.25 W m^{-2} (5.65%)	18.13 W m^{-2} (5.61%)
Coastal	1513	-0.51 W m^{-2} (-0.15%)	16.99 W m^{-2} (5.03%)	16.97 W m^{-2} (5.02%)
Island	2220	4.52 W m^{-2} (1.10%)	15.34 W m^{-2} (3.73%)	14.61 W m^{-2} (3.55%)
Polar	9681	-3.67 W m^{-2} (-1.66%)	26.05 W m^{-2} (11.79%)	23.56 W m^{-2} (10.66)

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